	<p style="text-align: center;">US ATLAS HL-LHC Upgrade BASIS of ESTIMATE (BoE)</p>		Date of Est: 24-Nov-2015
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			Docdb #:
WBS number: 6.5.2.5, 6.5.4.5		WBS Title: Tile LVPS Production	
WBS Dictionary Definition: <p>This WBS covers the production of the Low Voltage Power Supply for the ATLAS Tile Calorimeter HL-LHC upgrade. This version of the LVPS has one single type of +10v “brick”, with 8 bricks mounted in a “Finger PS box” (LVBOX). The University of Texas/Arlington group will produce 50% of the needed bricks, and the Northern Illinois University group will construct 50% of the needed boxes and mount the bricks in them.</p> <p>The primary deliverable for WBS 6.5.y.5 is production of 1,024 bricks over a two-year period, assembling them into 128 boxes, testing, and shipping to CERN. Additional tasks include a 10% pre-production run, parts procurement, assembly, testing and repair, and elevated temperature burn-in of the bricks. The bricks will be shipped to NIU for inclusion in boxes, testing and shipping to CERN.</p>			
Estimate Type (check all that apply – see BOE Report for estimate type by activity): <input type="checkbox"/> Work Complete <input type="checkbox"/> Existing Purchase Order <input type="checkbox"/> Catalog Listing or Industrial Construction Database <input checked="" type="checkbox"/> Documented Vendor Estimate based on Drawings/ Sketches/ Specifications <input checked="" type="checkbox"/> Engineering Estimate based on Similar Items or Procedures <input type="checkbox"/> Engineering Estimate based on Analysis <input checked="" type="checkbox"/> Expert Opinion			
Supporting Documents (including but not limited to): <p>Attachments: 1) ATLAS TileCal LVPS System Production Plan (2) ATL-TILECAL-PROC-2012-011 3) 3) ATL-TILECAL-PROC-2013-060</p>			

Details of the Base Estimate For 6.5.2.5 Brick Production

This BOE covers the production of 50% of the LVPS bricks required to operate the TileCal. The effort includes purchasing components and PCBs for the 1024 units needed, assembly testing and shipping of the boards to NIU, where they will be incorporated into 8-unit boxes and shipped to CERN.

This project relies heavily on the excellent work done by Argonne National Labs Jimmy Proudfoot and Gary Drake on V7.5 brick production and check-out, profiting from several man-years of work. In addition the new brick V8 prototype has already been produced by Argonne. Experience acquired during production of V7.5 bricks and prototype bricks for a “demonstrator module” proved that the assembly process by outsourced firms can be

successful if monitored by an experienced Electrical Engineer (EE) who can aid in debugging faults in the process. It is also important for a trained Electronics Technician to perform an initial test on bare PCBs and again as they arrive from the assembly house to detect and repair faults. The assembled boards are received from the vendor at the University of Texas, Arlington, where they are individually subjected to an array of tests using the brick test stand (BTS) developed by Argonne. Groups of 8 bricks are subsequently subjected to burn-in, at the BBIS brick burn-in test station. The burn-in test helps ensure the robustness of the bricks.

Materials Costs

Approximately 10% of bricks require repairs ranging from minor component swaps that can be identified and repaired by an undergraduate student or an ET to more complex failures requiring an EA or an EE to diagnose and repair. At least half of the 10% of non-trivial failures should be repairable with reasonable effort based on V7.5 experience, it is not obviously worth extreme effort, given the high reliability standards required due to limited access for extended periods of time. We thus assume a 90% yield and plan to produce 1140 boards.

To properly prepare for production in 2020, we plan to have a 10% pre-production run. We will purchase all the components for 114 boards; assuming a 90% yield based on past ANL experience, we would have 104 good boards (10% of 1040)--see Table 1. We will replace any obsolete components with the latest versions in order to make sure that the pre-production run is as close as possible to the production run. Procurement will be done by the EA in consultation with the engineer. For pre-production, we have applied a 20% higher cost for components and 50% for assembly than the estimated production cost, based on past experience at ANL.

Item	Cost for 2080 bricks	FY2020 UTA Production Cost (1144)	FY2019 Pre-prod. Cost (114)
Stock parts	350,000	193,000	23,100
Transformer	20,000	11,000	1,320
Thermal post	72,000	39,600	4,750
PCB Fab	20,000	11,000	1,320
PCB Assembly	200,000	110,000	16,500
Request		364,000	47,000

Table 1 Estimated materials cost of brick production and brick test and burn-in stations

The cost of materials for the pre-production, and production are derived from Gary Drake's estimates for the full board production. We will follow Gary's recommendation about using the same vendors for custom parts, and for the PCB board fabrication and assembly, these will help keep the cost down and maintain the high level of reliability. We will coordinate any joint purchases with our foreign collaborators to keep the cost as low as possible.

Labor Cost

Labor FTEs are estimated starting from experience with the recent V8 prototypes and V7.5 bricks (see Gary Drake's note) produced for the demonstrator, however, his estimate did not take into account that their group has been doing

the project for years, so it is a serious underestimate. Below, we also take into account the turn-on curve as the UTA group develops expertise. There will be a lead electrical engineer (a professor) who will oversee this project starting from 2016. To keep him on for the entire period since he will become the expert through early collaboration with Argonne National Labs we are required to pay him 2 months of summer salary. He will also be responsible for repairs, parts procurement, and of course management of the production. He will also be responsible for training new personnel since we will not have a constant work force. Our estimates also take into account the turn-over of man-power. We will rely on an electronics technician for some repairs and most of the checkout will be done by students with some support from the electronics technician.

A cost summary for WBS 6.5.2.5 is tabulated below.


 6.5.2.5	Deliverable	Task	Labor Hrs	Labor \$	M&S \$	Travel \$	Total \$
	LVPS Production		7,687	261,742	336,500	6,000	604,242
	Parts Procurement	LV2120	444	18,733	221,000	0	239,733
	Engineering labor		222				
	Student labor		222				
	PCB Fab and assy	LV2130	222	11,583	110,000	6,000	127,583
	Engineering labor		222				
	Student labor		0				
	Basic checkout and burn-in	LV2140	5,698	125,856	0	0	125,856
	Engineering labor		370				
	Student labor		5,328				
	Repairs	LV2150	691	59,908	2,500	0	62,408
	Engineering labor		691				
	Student labor		0				
	Management	LV2160	592	43,544	0	0	43,544
	Engineering labor		296				
	Student labor		296				
	Shipping	LV2210	40	2,118	3,000	0	5,118
	Engineering labor		40				
	Student labor		0				

Table 2 Amount and cost of labor summary for WBS 6.5.2.5

Schedule:

ATLAS management has scheduled installation of the Tile Calorimeter modules to begin early in 2024; possibly even late 2023. Consequently, the complete number of 256 tested and assembled drawers must be ready by 2024. To meet this target with available manpower and resources, 18 months of production are necessary over two years; this also provides for a comfortable 6 month schedule float. These requirements call for the following timeline:

- 2016-17: transition period, where knowledge will be transferred from ANL to UTA via Gary Drake, a 1% pre-production run for early identification of any unexpected issues. A new burn-in station will be designed possibly in collaboration with Prague
- 2019: final design and prototype pre-production
- 2020: parts procurement, production and testing of about 550 bricks (a quarter of the total required)
- 2021: production and testing of the second half the remaining bricks
- 2020-2021: NIU puts groups of 8 bricks in box and ships boxes to CERN
- 2022: acceptance testing at CERN and mounting on drawer structures
- 2023: full system testing and start of installation

Assumptions for 6.5.2.5:

- Adequate funding for transition by operations or other pre-construction sources
- Vendors of custom parts, PCB, boards, and assembly remain in business
- Brick failure < 10%
- Burn in fixtures supplied by collaborators

Risk Analysis for 6.5.2.5

We note that the recent production of a demonstrator prototype employing this brick design, and extended successful operation with very low failure rate over a couple years of accelerator operations leads to high confidence in performance and cost. The transfer of production to new groups has inherent risk, which could potentially involve delays. Labor costs are less well known than equipment. New modifications to the ELMB card or anything else that required a significant design change would cause an increase in personnel costs and schedule issues.

Schedule Risk:

Probability: Low

Potential Problem: The transfers of the brick/box production from Argonne to UTA /NIU naturally increases schedule uncertainty. It not only requires new expertise but also coordination that was not necessary when Argonne was the sole institute.

Mitigation: ANL engineer Gary Drake will help with transition and will remain associated with the overall TileCal upgrade. A planned 1% pre-pre-production run in 2017 will give early test of transition success and leaves copious amounts of time for course corrections, as this will occur more than a year prior to a one year 10% pre-production run. Further schedule float of up to half a year is expected (lag time for completion of 32 bricks before shipping to NIU should be less than two weeks). Failure modes will be known well in advance. There is no significant external dependency for brick production and the recent demonstrator production gives knowledge of the failure rate and assembly/testing time.

Cost Risk:

Probability: Low to moderate

Potential Problem: Although the prices for components is quite well known, the labor costs are less certain, due to the lack of direct experience with this project. If the brick failure rate were higher than expected, they would require more repair, or if a component were to become obsolete or in short supply there could be increased costs.

Mitigation: Use pre-production runs to gain experience and lower the time per brick prior to production run. Recent experience in TileCal, with the demonstrator and purchase of components validates costing. Component costs should be well within 30% contingency. Labor rates include 3% inflation, likely a bit of an over-estimate.

Technical/Scope Risk:

Probability: Low

Potential Problem: Card component no longer radiation qualified.

Mitigation: Find alternative component.

The technical risks are negligible: components are not exotic, with many alternatives. Radiation testing already virtually certifies the components chosen. It works. Our internal scope risk, is negligible, we will build half the bricks. The only way our scope increases is if we were asked to do more than we propose due to external issues.

Details of the Base Estimate For 6.5.2.5 Brick Production

This part of the BOE covers the production of 50% of the LVBOXes needed for the detector. It includes procurement of all components, assembly, basic checkout and burn-in, repairs, and shipping of 128 units to CERN. The LVBOXes supply low-voltage power to the Tile Calorimeter front-end electronics. Each water-cooled LVBOX contains eight DC/DC single-output modules (“brick”s) transforming 200VDC input into a +10v feed to the Main Boards on the Tile drawers. Other components of a LVBOX are a 200VDC distribution Fuse-Board, internal cable set, a water cooled heatsink, and a local control and communication board (the ELMB Motherboard). Mounted in the vicinity of drawers inside so called “FINGERS”, the LVBOXes are exposed to radiation and magnetic field in the ATLAS cavern.

Estimates for the cost of the components and assembly by commercial vendor are based on extrapolation of the last exercise done in 2011. Each LVBOX is estimated to cost \$900 (not including the bricks and ELMB motherboards), accounted for as follows:

1. Chassis: \$200,
2. Cold plate: \$100,
3. Fuse board: \$100,
4. Connectors, cables etc (including fabrication): \$400,
5. Assembly: \$100.

Some of these cannot be split among the two institutions sharing the task (work by one, namely NIU, is proposed here, while the other is in Europe). For maximum uniformity, the procurement of each component is assigned to a single institution, with #3 and #4 to NIU.

Labor FTEs are based on experience from previous campaigns. They are broken down as follows (NIU component only):

- Vendor selection, component selection and BoM: 40 hrs EE in Y1, 40 hrs ET in Y1, Y2
- Burn-in and basic checkout: 40 hrs EE + 40 hrs ET + 160 hrs undergraduate student, in Y1,Y2
- Diagnose and repair failures: 40 hrs EE + 40 hrs ET, in Y1,Y2
- Inventory, crate and ship to CERN: 40 hrs ET, in Y2

Travel to CERN by the EE and ET are needed during the production phase. A total of three week-long trips are estimated.

A cost summary for WBS 6.5.4.5 is tabulated below.

WBS	Deliverable	Task	Labor Hrs	Labor \$	M&S \$	Travel \$	Total \$
6.5.4.5	LVPS Assembly		1,576	118,660	156,000	3,855	278,515
	Test equipment	LV4060	480	43,175	20,000	0	63,175
	Engineering labor		480				
	Student labor		0				
	Production procurement	LV4120	136	10,285	128,000	0	138,285
	Engineering labor		136				
	Student labor		0				
	Production Assembly	LV4130	120	9,753	0	3,855	13,608
	Engineering labor		120				
	Student labor		0				
	Production burn-in and checkout	LV4140	480	23,015	4,000	0	27,015
	Engineering labor		160				
	Student labor		320				
	Production diagnostics and repair	LV4150	320	30,092	4,000	0	34,092
	Engineering labor		320				
	Student labor		0				
	Shipping	LV4210	40	2,341	0	0	2,341
	Engineering labor		40				
	Student labor		0				

Table 3 Amount and cost of labor summary for WBS 6.5.4.5

Schedule for 6.5.4.5:

- 2018-19: final design and prototype pre-production (not costed in this document)
- 2020: parts procurement, construction of test bench
- 2021: assembly and testing of 64 LVBOXes
- 2022: assembly and testing of 64 LVBOXes
- 2022: delivery of all LVBOXes to CERN

Assumptions for 6.5.4.5:

- Preproduction funded by operations or other pre-construction sources
- Timely receipt of ELMB++ boards from MSU
- Timely receipt of LV bricks from UTA
- Component failure rate < 10%

Risk Analysis for 6.5.4.5:

Schedule Risk:

Probability: Low

Potential Problem: higher component failure rate.

Mitigation: 33% schedule float should be sufficient to address any plausible failure rate.

External dependency is of routine nature. Rate and assembly/testing time are known from past production.

Cost Risk:

Probability: Low

Potential Problem: higher failure rate necessitating more repair, or increased component costs.

Mitigation: More EE labor to augment repair force; component costs should be well within 30% contingency.

Costing and debug times are estimated from past experience.

Labor rates include 3% inflation.

Technical/Scope Risk:

Probability: Negligible

Potential Problem: Design fault in one or more components,

Mitigation: Find alternative components.

The components are mostly off-the-shelf, with many alternatives.

M&S Contingency Rules Applied

50%

We now estimate the contingency based on the rules for M&S. It depends on the maturity of the cost estimate.

5) 40-60% contingency on: items with a detailed conceptual level of design; items adapted from existing designs but with extensive modifications, and/or made more than 2 years previous with documented costs. A physicist or engineering estimate uses this level.

Labor Contingency Rules Applied

50%

We now estimate the contingency based on the rules for Labor.. It depends on the maturity of the cost estimate.

40-60% contingency for a task that is not yet completely defined, but is analogous to past activities; for example, a fabrication activity similar to, but not exactly like, items fabricated for other activities; for example, design labor for items similar to, but not exactly like, previous designs.

Comments:

There is high confidence in the material cost estimate and technical issues due to the highly successful Argonne LVPS work. While the labor costs are less mature, since it is an entirely new project for UTA, we note that they represent only 45% of the total cost.